Quarterly Progress Report

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THE EFFECT OF STRESS FIELDS ON THE ULTRASONIC ENERGY REFLECTED FROM DISCONTINUITIES IN SOLIDS

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This progress report is preliminary and is not to be considered as part of the technical literature. The information contained within is tentative and is subject to change or modification.

I. Introduction

The integrity and performance of materials in service are highly dependent upon the critical nature of material defects and the behavior of these defects under service conditions. Analytical procedures (e.g. notch analysis and fracture mechanics) have been developed to provide methods for predicting the strength or load-carrying capacity of a structural part in the presence of known defects. Effective use of these procedures, however, requires that the defects be characterized as to their location, their true size and shape and their orientation with respect to the direction of principal stresses as expected from the service loads.

In view of the increasing need for improvement in the detection and characterization of defects in structural materials, the challenge to the field of nondestructive testing is to develop procedures capable of resolving defects of critical size and to accurately define defect geometry. To meet this challenge, many investigators in this field are currently engaged in research to develop new NDT techniques (some of which are extremely sophisticated) or to provide improvement in the detection and characterization of defects by modification of the more conventional NDT methods.

The NDT research program now in progress in the Syracuse University Research Corporation, Materials Science Laboratories (SURC-MSL), is of the last-mentioned type; a modification of the ultrasonic pulse-echo method of flaw detection. The approach is based on the principal that when a stress field is applied to a discontinuity (defect or flaw) in a solid, a change in the geometry of the discontinuity is effected. The change in geometry can result in corresponding changes in amplitude and/or pattern of ultrasonic energy reflected from the discontinuity. It is reasonable to expect that the reflected energy response should be relatable to specific distinguishing features of a given type of discontinuity.

The present studies are a continuation of earlier studies (1) (2) at SURC-MSL to investigate the effect of stress fields on the ultrasonic energy reflected from thin flat cracks in solids. These studies have clearly demonstrated that the amount of ultrasonic energy reflected from thin flat cracks in steel, aluminum and glass is very sensitive to small changes in stress intensity at the crack tip. Thus, the detection of thin cracks with pulse-echo is enhanced by tensile stress in the crack region. This effect of tensile stress on reflected energy can be very useful provided that the factors involved are well understood. For example, in addition to improved detection of small thin cracks, it has also been shown that this effect can be useful for improved accuracy in determining true crack size with pulse-echo. When used in conjunction with crack tip stress analysis (e.g. fracture mechanics), this information can provide greater confidence in the design against premature failure of military vehicles and structures.

Analyses of the information obtained from the studies on thin flat cracks have shown that the observed variation in reflected energy are due to changes in crack geometry (particularly, crack opening) which are influenced by modification of the stress field in the vicinity of the crack. For this response to occur, the initial crack opening must be within a critical range of values, and it has been shown that this critical range is a function of acoustic impedance mismatch at the crack interface and also the frequency of the ultrasonic input pulse.

In principal, similar effects can be expected when stress is applied to defect geometries other than thin cracks, and the reflected energy response should be relatable to changes in geometry as a function of applied stress.

II. Objectives of the Program

The objective of the present research efforts at SURC-MSL is to investigate the effect of stress fields on the degree and pattern of ultrasonic energy reflected from various types of discontinuities (defects or flaws) in solid materials. It is expected that the information obtained in these studies will provide improvement in the capability to characterize specific types of defects as to size and severity using ultrasonic techniques.

III. Research Program and Plan

The technical program consists of experimentation and analyses to determine the effect of stress field changes on the degree and pattern of ultrasonic energy reflected from various types of discontinuities in solids. Efforts are made to correlate the information obtained with specific distinguishing features of a given type of discontinuity.

A. Procedures

The initial experiments consist of tests on metal specimens prepared with flaws of simple geometric shapes such as cylindrical sections (e.g. to simulate holes, voids and porosity) and slots of various depth and width (e.g. to simulate nonmetallic inclusions, segregations, delaminations and cracks). Concurrent with these experiments, efforts will be made to obtain metal samples containing typical flaws from industrial and other possible sources, utilizing material rejected through NDT practice. Specimens made from these metal samples will be tested to allow comparison of stress effects on typical flaws to that obtained on simple geometric shapes. These studies will be augmented by tests on specimens containing typical flaws that can be produced in the laboratory, (e.g. fatigue cracks, quench cracks and weld imperfections).

For each type of flaw configuration, measurements of the change in ultrasonic echo amplitude will be made as a function of load applied to the specimen. Changes in echo signal pattern will also be noted to determine if specific features of a given type of flaw are revealed by pattern changes.

To obtain meaningful information from these tests, it will be necessary to provide for careful control of ultrasonic parameters. Therefore, a complete record of ultrasonic instrument control positions and associated components will be maintained for each test performed. Included among these parameters are frequency, mode and rate of input pulse; size and type of search unit; gain sensitivity, amount of reject, sweep and type of scan employed and the specific methods of coupling search unit to specimen.

B. Materials

The materials to be included in the program are steel alloys, aluminum alloys and glass. Steel and aluminum are chosen because of the structural significance of these alloys in the design and construction of military vehicles and hardware. Also, steel and aluminum alloys have excellent ultrasonic characteristics (such as low attenuation), and can be heat treated to different levels of strength and ductility. Glass is included because, under stress, the behavior of glass is nearly elastic for loads up to the breaking point. Thus elastic analyses can be applied directly to data obtained on glass, and plasticity corrections are normally not required. Also, glass is an excellent material for crack studies because, in glass, crack geometry is relatively easy to define, and crack opening displacement can be measured by means of optical interference techniques.

IV. Summary of Work Performed

Test specimens containing discontinuities of simple geometric shapes (thru holes and slots) were prepared from AISI 1020 steel plate. These specimens were designed so that both axial tension and cantilever bend loading can be employed in the tests. The initial tests were performed on the steel specimens containing thru cylindrical holes of various diameters. For a longitudinal wave input normal to the axis of the hole, it was found that a very small change in echo amplitude occurred as stress was applied to the plate. The response is a function of the change in curvature of the reflecting interface at the hole. An increase in hole diameter results in an increase in echo amplitude. It was also found that when the ultrasonic beam (longitudinal wave) is directed to the hole normal to the direction of principal stress, tensile stress causes a decrease in curvature and a corresponding increase in echo amplitude.

Tests on steel specimens containing thin slots are now in progress. Some difficulties were encountered in producing slots sufficiently thin for the intended purpose. This problem was resolved to some extent by introducing slots with Elox electrical discharge machining techniques. The purpose of the tests on specimens with thin slots is to verify that ultrasonic reflected energy can be affected by changes in slot opening, depending upon the input pulse frequency and the acoustic impedance mismatch at the interface. Plans are to change the mismatch by introducing various media (e.g. water, oil etc.) into the slots during the tests. For the range of input pulse frequencies available with present equipment (1.0 to 10.0 MHz), it is necessary that the slot openings be of the order of magnitude of 5 mils.

In addition, a specimen of aluminum alloy 7075-T6 is being prepared to further evaluate the effect of air film thickness. This specimen has been designed to include a carefully prepared flat bottom

hole of 0.125 inch diameter, in which the stem of a barrel micrometer can be inserted. In this manner an air gap of variable thickness is obtained by rotation of the micrometer barrel. The experiments will be performed with normal contact search units placed at a constant metal travel distance from the bottom of the hole.

Plans to solicit metal samples containing typical flaws from industrial and other sources have been initiated. A section of heavy (3 inch thick) hot rolled steel plate containing a longitudinal seam, and an aluminum casting containing large voids have been acquired to date.

Also during the quarterly period, several tests were conducted on plate glass specimens containing very thin surface cracks. These tests were conducted as part of an effort to utilize the relationship between stress intensity at the crack tip and reflected ultrasound from the crack interface to improve accuracy in measuring true crack size. The analyses and experimentation performed in these studies, together with the results of earlier studies (3), have provided the basis for a Masters' thesis prepared by Mr. Mukul Sengupta, a graduate student in the Department of Chemical Engineering and Metallurgy at Syracuse University. Mr. Sengupta is associated with the present research program as Graduate Research Assistant. It is planned that the information contained in the thesis will be presented in an Interim Technical Report.

V. Projected Effort

In the second quarterly period, measurements of ultrasonic energy reflected from discontinuities of simple geometric shape (holes and slots), as a function of varying stress field, will be continued. Experiments to evaluate the effect of air film thickness will be conducted using the flat bottom hole specimen designed for this purpose. Data obtained from these experiments will be compared to that which is predicted from thin film equations based upon acoustic wave theory.

Efforts to acquire additional metal samples containing typical flaws from industrial sources will be continued. Also, during the second quarterly period, it is planned to prepare several metal specimens with certain types of defects that can be produced in the laboratory, including fatigue cracks, weld imperfections (such as incomplete penetration, slag inclusions and lack of fusion) and possibly quench cracks.

VI. Problems Encountered

No major problems were encountered during the first Quarterly Report period.

VII. Fiscal Status

The current fiscal status of the program is as follows:

1.	Amount currently funded	$44,900
2.	Estimated expenditures and commitments to date	9,400
3.	Estimated funds required to complete the program	35,500

VIII. Action Required by Government

None at present.

IX. Personnel

Mr. John G. Sessler is serving as Principal Investigator and is assigned to the program for 75 percent time. He is assisted by Dr. Volker Weiss who is available a minimum of 5 percent time. Mr. Mukul Sengupta, graduate student in the Syracuse University Department of Metallurgy, is available to the program 50 percent time (academic) and 100 percent time (recess). Mr. Sengupta will fulfill the requirements

for a Masters degree in Solid State Science at the University in February 1971 and his thesis will be based on research efforts performed in conjunction with the present program.

Mr. Leland Barrus is assigned to the program full-time as electronic and NDT technician. In addition, machine shop and reproduction services are available to the contract as needed.

Respectfully submitted

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References

1) J.G. Sessler and V. Weiss, "Improvement in Flaw Detection by the Ultrasonic Pulse-Echo Technique With Simultaneous Low Frequency Excitation", Final Report, ARPA Contract N00140-69-C-0121, Syracuse University Research Corporation (Nov. 1969).

2) J.G. Sessler and V. Weiss, "Improvement in Crack Detection by Ultrasonic Pulse-Echo With Low Frequency Excitation", Final Report, ARPA Contract N00140-70-C-0223, Syracuse University Research Corporation (Oct. 1970).

3) J.G. Sessler, "Improvement in Crack Detection by Ultrasonic Pulse-Echo With Low Frequency Excitation", Semi-Annual Report, ARPA Contract N00140-70-C-0223, Syracuse University Research Corporation (May 1970).